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Performance Report:
Micro-Combustion for Nano and Pico Satellite Propulsion Systems
AFOSR F496200110435

September 1, 2002

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Introduction

This research investigates the physics of micro-scale fluid-structure coupling in reacting flow systems for the purpose of developing efficient micro-rocket motors. It is motivated by the US Air Force's need in the coming decade for compact propulsion devices suitable for positioning and attitude control of micro-satellites and other micro-scale space vehicles. While there is a range of technologies that are available for this purpose, chemical rockets remain extremely attractive because of the high energy density of their fuels. However, constructing efficient chemical rocket engine combustors becomes difficult as the size of the motor is reduced. The problems stem from the strong coupling between fluid and structure that exists at small scales: Heat loss and radical quenching at the walls makes it difficult to stabilize and sustain efficient combustion. This research program is in the process of developing appropriate models and acquiring experimental data that will be used to identify the physical parameters and processes that distinguish micro-combustion from combustion at conventional scales.

1. Objectives

- Develop models that are appropriate for predicting the performance of millimeter-scale combustors
- Develop experimental techniques for making non-intrusive measurements of species concentration and temperature in micro-combustors
- Design and construct a parallel plate reactor suitable for investigating fluid-structure coupling in micro-combustors
- Develop a novel diagnostic technique based on infrared spectroscopy that is capable of making non-intrusive measurements of species concentration and temperature in reacting micro-channel flows by looking through the silicon walls.
- Measure species concentration and temperature profiles in parallel-plate reactor and compare with model predictions.

2. Status of Effort

- The analytical model is being improved to account for non-continuum effects on the heat transfer coefficient between the walls and the gas.
- The numerical model is being used to identify optimum micro-combustor configurations
- The following steps are being taken to improve the non-intrusive diagnostic technique:
 - A new, higher resolution, FTIR is being acquired
 - Spatial resolution is being improved from 4mm x 4mm to 1mm x 1 mm
 - Data processing/interpretation techniques are being improved.
 - A higher efficiency external optical system is being developed

3. Accomplishments/New Findings

- An Analytical model for the behavior of a combustion wave stabilized in a micro-channel has been developed and has been shown to agree qualitatively with the predictions of the more comprehensive numerical simulation. This demonstrates that heat transfer from the post-flame to the pre-flame through the structure plays a critical role in governing the burning rate and reaction zone thickness in micro-combustors.
- Heat transfer in the structure has the following effects:
 - Increases the overall reaction rate
 - Increases the reaction zone thickness
- The passage height at which thermal coupling between gas and structure becomes important is determined by the Nusselt number. For H₂-air combustion between two parallel plates, thermal coupling with the structure starts to become important at passage heights of 1mm and less.
- The magnitude of the effect of heat transfer through the structure on the burning rate and reaction zone thickness is governed by the conductance (ie. the product of the thermal conductivity times the cross-sectional area) of the micro-combustor structure. Increasing the conductance increases the reaction rate or the flame thickness.
- Reaction rate and reaction zone thickness cannot be increased arbitrarily by decreasing combustor passage height. Instead, these follow a limit cycle behavior where at large passage heights the reaction rate and reaction zone thickness are dominated by the properties of the gas and at small passage heights the reaction rate and reaction zone thickness are dominated by the properties of the structure.
- The viability of the infrared diagnostic technique has been demonstrated by making non-intrusive measurements of species concentration and temperature in a silicon-walled micro-combustor.

4. Personnel Supported:

- Timothy Leach (Graduate Student)
- Scott Heatwole (Graduate Student)
- Christopher Cadou (Faculty)

5. Interactions:

- Work presented at AFOSR contractors' meeting August 2002, Colorado Springs
- Collaborating with Richard Yetter at Penn State to apply the non-intrusive diagnostic technique to the flows in his micro-swirl combustor.

6. New Discoveries, Inventions, Patent Disclosures:

None